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EVALUATION OF TWO AUTOMATIC SIGNAL DETECTORS USING THE KOREAN SEISMIC RESEARCH STATION SHORT-PERIOD ARRAY

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TECHNICAL REPORT NO. 3

VELA NETWORK EVALUATION AND AUTOMATIC PROCESSING RESEARCH

Prepared by
Wen-Wu Shen

TEXAS INSTRUMENTS INCORPORATED
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Post Office Box 6015
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Prepared for

AIR FORCE TECHNICAL APPLICATIONS CENTER
Alexandria, Virginia 22314

Sponsored by

ADVANCED RESEARCH PROJECTS AGENCY
Nuclear Monitoring Research Office
ARPA Program Code No. 6F10
ARPA Order No. 2551

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Acknowledgment: This research was supported by the Advanced Research Projects Agency, Nuclear Monitoring Research Office, under Project VELA-UNIFORM, and accomplished under the technical direction of the Air Force Technical Applications Center under Contract Number F08606-76-C-0011.

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Fisher and conventional automatic seismic signal detectors were evaluated for their detection performance with data from the Korean Seismic Research Station (KSRS). A total of 330 events recorded in November 1974 and January-February 1976 was used as a data base. The detectors were run with 0.8 and 1.6 second integration gates. The capability of both detectors to successfully detect and time seismic events was compared with the performance of a seismic analyst. The conventional (array beam)

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power detector was found superior to the Fisher detector. A conventional power detector installed at KSRS could achieve a seismic analyst's detection performance, but possibly at a higher false alarm rate than the analyst.

ABSTRACT

Fisher and conventional automatic seismic signal detectors were evaluated for their detection performance with data from the Korean Seismic Research Station (KSRS). A total of 330 events recorded in November 1974 and January-February 1976 was used as a data base. The detectors were run with 0.8 and 1.6 second integration gates. The capability of both detectors to successfully detect and time seismic events was compared with the performance of a seismic analyst. (The author found The conventional (array beam) power detector was found superior to the Fisher detector. A conventional power detector installed at KSRS could achieve a seismic analyst's detection performance, but possibly at a higher false alarm rate than the analyst.

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SECTION I
INTRODUCTION

This report presents results of a study of two automatic signal detectors using short-period data from the Korean Seismic Research Station (KSRS). One is the conventional power detector, which computes the ratio of short-term average beam power to long-term average beam power as the detector output. The other is the Fisher detector, which computes the ratio of short-term average beam power to short-term average variance across the array (Lane, 1974; Swindell and Snell, 1976).

The detectors were adaptive, using a constant alarm rate algorithm to continuously update the detection thresholds. Objectives herein are as follows:

- Estimate seasonal variations of detection performance
- Estimate regional variations of the detector performance
- Compare automatic and seismic analyst's performance
- Compare conventional and Fisher detector performance.

The objectives were accomplished by studying a total of 330 events from Eurasia. Section II presents a brief description of the KSRS array and the data base used in this study. Methodological presentation of detector's correct decision probability is given in Section III. Results are presented in Section IV where detailed description is given in terms of operational parameters, detection performance in autumn and in winter, detection time accuracy, and false alarms. Conclusions and suggestions are given in Section V.

SECTION II
DATA BASE

A. ARRAY

The Korean Seismic Research Station (KSRS) short-period array consists of nineteen vertical sensors and has an aperture of about 10 kilometers (km). Maximum instrument response centers at 1 Hz with static gain at 0.488 millimicrons (mμ) per digital computer count. Refer to Prahl (1975) for details of the array configuration and the instrument response curve.

B. DATA BASE

Data used for the evaluation were from two periods: one was November 1974 (149 events) and the other was January-February 1976 (181 events). The November 1974 data had been previously used by Black and Lane (1975) for a detector design study. The data were needed here again to study the seasonal performance in the autumn season. For the winter season, data were taken from 15 January to 20 February 1976.

SECTION III

DETECTOR'S CORRECT DECISION PROBABILITY

In the present evaluation of the Fisher detector and the conventional power detector, the detectability estimate was treated as a statistical problem, based on detection performance evaluation of a large ensemble of events. The detectors were adaptive and designed to operate at a constant alarm rate. Part of the detections obtained can be false alarms triggered by noise alone. Also, some signals will be missed and interpreted as noise. This section describes how these problems can be corrected statistically (Wainstein and Zubakov, 1962; Horton, 1969).

Let $p(m)$ be the a-priori probability of a signal occurrence when the detector declares an alarm and let $p(o)$ be the a-priori probability of no signal occurrence when the detector declares an alarm. Then, $p(m)$ and $p(o)$ are the a-priori probabilities which are associated with:

$$p(m) + p(o) = 1 .$$

For the work in this report, $p(o)$ is 0.055 as deduced from a false alarm rate of 10 per hour and a 40 second gate for two beams, and is 0.111 for the single sensor (or single beam).

Consider the possible states of a detector. First, when a signal is present, the detector can correctly claim a detection or can incorrectly dismiss the signal. The former situation is called the "correct detection," D, and the latter the "incorrect dismissal," D_o:

$$D(m_b) + D_o(m_b) = 1.$$

Second, when a signal is not present, the detector correctly dismisses noise, or incorrectly claims a detection. The former situation is called "correct non-detection," F, and the latter "incorrect detection" (or false alarm), F_o, with the two probabilities being associated with the relation:

$$F(m_b) + F_o(m_b) = 1 .$$

D and F are associated with conditional correct detections, while D_o and F_o are associated with incorrect detections. Finally, the unconditional correct decision probability is given by Wainstein and Zubakov (1962, Chapter 5 and Appendix 1):

$$W(m_b) = p(m)\,D(m_b) + p(o)\,[1 - F(m_b)] .$$

The a-priori probabilities p(m) and p(o) can be estimated from the prescribed alarm rate used for the detector, while $D(m_b)$ and $F(m_b)$ must be obtained from experimental data.

To obtain $D(m_b)$ and $F(m_b)$ for the Fisher detector and the conventional power detector, adaptive beamforming (ABF) processing was performed on the central Eurasian events in November 1974 and for the Kurile-Kamchatka events in January and February 1976. The beamforming was performed on "expected" signals that were not visible on single-sensor data. These processing results were used as criteria in deciding whether a signal was present or not. These results were checked against detection logs to estimate $D(m_b)$ and $F(m_b)$.

$W(m_b)$ was used to correct the experimentally observed detectability, $G(m_b)$. The corrected value of the detectability was then computed as follows:

$$G_c(m_b) = G(m_b)\,W(m_b) .$$

The final Gaussian parameters (μ, σ) of detection probability were estimated by use of the "least-squares" error fitting method for $G_c(m_b)$ (Bevington, 1969).

Table III-1 shows the Gaussian parameters for the correct decision probability estimated by the least-squares method for the central Eurasian events in November 1974, and Table III-2 for the Kurile-Kamchatka events in January and February 1976.

TABLE III-1

GAUSSIAN PARAMETERS FOR CORRECT DECISION PROBABILITY
(CENTRAL EURASIAN EVENTS, NOVEMBER 1974 DATA)

Detector	Integration Gate (second)	Mean or 50 Percent Detectability (m_b)	Standard Deviation (m_b)
Fisher	0.8	3.55	0.55
	1.6	3.44	0.45
Conventional Power	0.8	3.46	0.49
	1.6	3.55	0.65

TABLE III-2

GAUSSIAN PARAMETERS FOR CORRECT DECISION PROBABILITY
(KURILE-KAMCHATKA, JANUARY AND FEBRUARY 1976 DATA)

Detector	Integration Gate (second)	Mean or 50 Percent Detectability (m_b)	Standard Deviation (m_b)
Fisher	0.8	3.62	0.58
	1.6	3.67	0.42
Conventional Power	0.8	3.66	0.41
	1.6	3.80	0.38
Single-Sensor Power	0.8	3.69	0.47
	1.6	3.70	0.40

SECTION IV
RESULTS

A. OPERATIONAL PARAMETERS

The detectors were designed to operate at constant alarm rates to adapt to the noise levels which were found varying significantly from time to time at the Korean Seismic Research Station (KSRS) short-period array (Lane, 1974). The design allows certain parameters to be set so that signal and noise characteristics can be properly utilized to achieve the optimum detection modes.

In general, the parameters used in this study were the same as used previously by Black and Lane (1975). Any changes to the parameters will be specifically stated in the following subsections as results are presented.

B. DETECTION PERFORMANCE IN AUTUMN

Evaluation of the detector's performance using the November 1974 data was done in two steps. First, automatic processing was performed on time windows containing a total of 149 events taken from the Preliminary Determination of Epicenters (PDE) and Large Aperture Seismic Array (LASA) bulletins. Second, a regional study using 37 events in central Eurasia was done in more detail for comparison with the adaptive beamforming (ABF) results.

1. Automatic Processing of 149 Events

For the work on the ensemble of 149 events, evaluation was done with a 0.8-second integration gate and 10 per hour false alarm rate. A

6-minute warm-up time, which is the time processed prior to the 'expected' signal arrival, was used. As a prefiltering process in order to optimize the signal-to-noise ratio for the KSRS short-period data, a time-domain filter, which was designed from the single-sensor signal and noise power spectra and therefore was called 'single-sensor' optimum detection filter, was used to filter the data before beamforming. Figure IV-1 shows its frequency-domain response. Both 120- and 30-second signal detection windows were studied with seven beams to cover the whole Eurasian area. These 149 events were also used for a detection study using single-sensor power detector. All detection results for this phase of study are presented in Table IV-1. In the table, the 'wide bandpass' was taken from the previous results of Black and Lane (1975).

A longer warm-up time of 12 minutes before the 'expected' signal arrival was also studied to see if it improved the detector's performance by use of a longer noise window. The whole 149 event ensemble was processed again with 12 minute warm-up time. Table IV-2 presents the 50 percent detectable m_b units for the 12-minute results. False alarm rate was considered in the probability estimate. When compared with the 30 second detection window in Table IV-1, practically the same results were obtained.

2. Regional Study Using 37 Central Eurasian Events

Regional study for the season was performed with a limited area in central Eurasia. A total of 37 events recorded in November 1974 was used. In order to examine the detector's performance in various frequency ranges, the other optimum detection filter which was designed on the basis of array beam signal and noise power spectra, and a low frequency passband (0.5 - 1.1 Hz) filter were also applied to prefiltering the data. For this event ensemble, the azimuths ranged from 257^{o} to 310^{o} and the epicentral distances ranged from 20^{o} (equivalent to 10 km/sec apparent velocity) to 78^{o} (equivalent

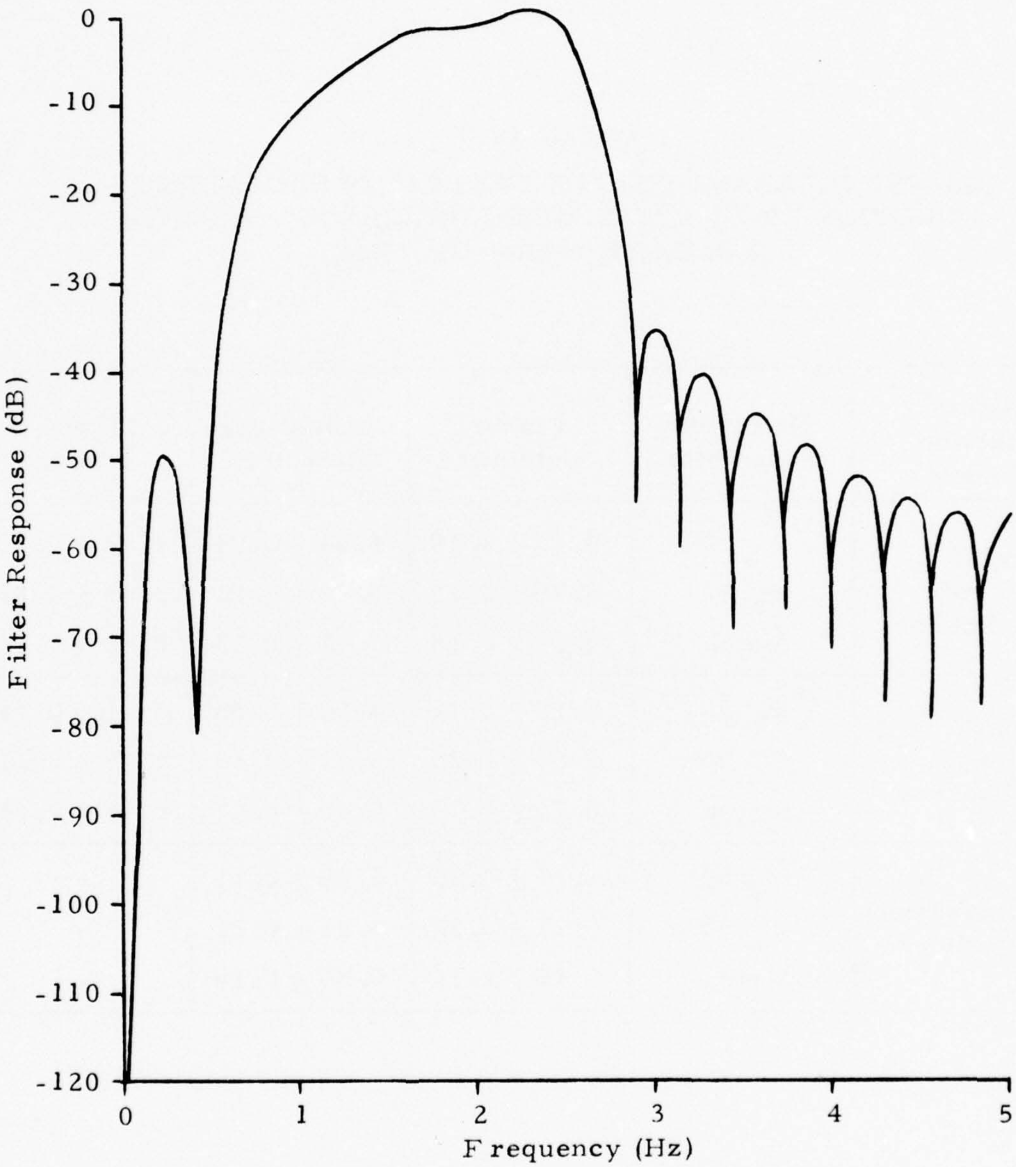

FIGURE IV-1

FREQUENCY RESPONSE OF SINGLE-SENSOR OPTIMUM DETECTION FILTER

TABLE IV-1

GAUSSIAN PARAMETERS OF DETECTION PROBABILITY FUNCTION FROM A MAXIMUM LIKELIHOOD ESTIMATE (6-MINUTE WARM-UP TIME)

Filter/ Detection Window	Detection Parameter	Fisher Detector	Conventional Detector	Single-Sensor
Optimum/ 120 seconds Single-Sensor	m_b 50	4.75 ± 0.10	4.64 ± 0.09	4.72 ± 0.10
	m_b 90	5.79 ± 0.25	5.59 ± 0.21	5.75 ± 0.25
	Sigma	0.80 ± 0.15	0.74 ± 0.13	0.80 ± 0.15
Optimum/ 30 seconds Single-Sensor	m_b 50	5.18 ± 0.12	4.90 ± 0.08	5.21 ± 0.14
	m_b 90	5.99 ± 0.25	5.53 ± 0.15	6.19 ± 0.31
	Sigma	0.70 ± 0.12	0.49 ± 0.07	0.76 ± 0.14
Wide Passband/ 30 seconds	m_b 50	5.21 ± 0.15	5.09 ± 0.11	-
	m_b 90	6.24 ± 0.33	5.86 ± 0.21	-
	Sigma	0.80 ± 0.16	0.59 ± 0.10	-

TABLE IV-2

COMPARISON OF 50 PERCENT DETECTABLE BODYWAVE MAGNITUDE FOR TWO DETECTORS (OPTIMUM SINGLE-SENSOR PREFILTER, 0.8 SECOND INTEGRATION GATE, 30 SECOND DETECTION WINDOW, 12-MINUTE WARM-UP TIME)

Detector	Fisher Detector	Conventional Power Detector
m_b	5.09 ± 0.14	4.79 ± 0.08
Constant False Alarm Rate *	1.43 per hour	1.43 per hour

* The constant false alarm rate in alarms per hour per beam prescribed for the detector's operation. This is not always realized in practice as shown by Table IV-9, which shows the alarm count for the sum of all of the beams (10 per hour in theory versus 4 per hour to 17 per hour realized).

to 20 km/sec apparent velocity). Therefore, only 270° and 300° beams with 50° epicentral distance (equivalent to 15 km/sec apparent velocity) were used.

The detectors shut off for one minute after a detection. Occasionally, a signal, weak or strong, might arrive within such a 'dead' period triggered by an alarm. As a result, a detection would be missed even if the detector output was significantly higher than some prescribed threshold. To evaluate this, detector outputs were examined and checked against the threshold. A detection was claimed if bin levels (detection statistic levels set to control the alarm rate) were at least 1 dB above the prescribed threshold for declaring an event arrival. In the 37 events processed, two of such cases occurred, suggesting that a better procedure is needed to control redundant coda detections.

Bin levels were adjusted to improve the constant alarm rate threshold estimation. For the Fisher detector, the lowest bin level was lowered from 4.8 dB to 0.0 dB with a 0.15 dB increment, and for the conventional power detector, from 9.8 dB to 4.8 dB with the same 0.15 dB increment. Outputs for both detectors were examined against the results using the previous bin levels for a number of events before ensemble processing was started. In general, the lowering of bin levels improved weak and medium event detections significantly.

Detailed results for this part of the work are presented in Table IV-3. When compared with the results in Tables IV-1 or IV-2, it indicates an improvement of about 1 m_b unit. This was caused by running this data with two beams as compared with seven beams in the preceding study (Subsection IV-B-1). The false alarm rate control mechanism adjusts the threshold so that the alarm rate of all of the beams combined is equal to the false alarm rate parameter, in our case, ten per hour. On per beam basis, results in the preceding study were therefore run at 1.43 per hour as compared to 5 per hour in this study. Thus the magnitudes derived pertain to

TABLE IV-3

MAXIMUM LIKELIHOOD ESTIMATES OF DETECTION PROBABILITIES FOR FISHER AND CONVENTIONAL POWER DETECTORS AT KSRS ARRAYS (ON THE BASIS OF 37 EURASIAN EVENTS IN NOVEMBER 1974, 30 SECOND DETECTION WINDOW, 12-MINUTE WARM-UP TIME)

Prefilter	Integration Gate (sec)	Fisher Detector			Conventional Power Detector		
		$m_b 50$ *	$m_b 90$ **	σ ***	m_b 50	$m_b 90$	σ
Low Passband (0.5-1.1 Hz)	0.8	4.78 ± 0.20	5.81 ± 0.52	0.80 ± 0.31	4.26 ± 0.19	5.28 ± 0.38	0.80 ± 0.31
	1.6	4.51 ± 0.16	5.45 ± 0.38	0.73 ± 0.26	4.45 ± 0.18	5.48 ± 0.42	0.80 ± 0.31
Wide Passband (0.5-3.5 Hz)	0.8	4.40 ± 0.14	5.19 ± 0.28	0.62 ± 0.20	3.75 ± 0.32	4.78 ± 0.30	0.80 ± 0.37
	1.6	4.24 ± 0.14	4.94 ± 0.22	0.55 ± 0.17	3.98 ± 0.24	5.00 ± 0.33	0.80 ± 0.34
Optimum: Array Beam (1.0-2.8 Hz)	0.8	4.12 ± 0.21	5.15 ± 0.36	0.80 ± 0.32	4.09 ± 0.13	4.70 ± 0.19	0.48 ± 0.16
	1.6	4.17 ± 0.15	4.95 ± 0.25	0.60 ± 0.20	4.25 ± 0.10	4.69 ± 0.16	0.34 ± 0.10
Optimum: Single Sensor (1.5-2.5 Hz)	0.8	4.10 ± 0.11	4.62 ± 0.18	0.41 ± 0.13	4.02 ± 0.16	4.70 ± 0.21	0.53 ± 0.19
	1.6	4.07 ± 0.21	5.03 ± 0.31	0.75 ± 0.29	4.01 ± 0.17	4.74 ± 0.22	0.57 ± 0.21

* 50% detectable bodywave magnitude
** 90% detectable bodywave magnitude
*** Standard deviation.

different false alarm rates. It must be mentioned that the single-sensor results will correspond to a false alarm rate of 10 per hour.

For the 37 events, the adaptive beamforming (ABF) and beamsteer processing were conducted and the results (signal presence or not) were used as references to check against the detector's results to obtain the detector's 'correct decision probability', discussed in Section III. A least-squares fitting technique, which incorporates the correct decision probability, was developed to estimate the Gaussian parameters for detection probabilities in terms of m_b units.

Figure IV-2 shows an illustration of the computation for the Fisher detector using the 0.8 second integration gate. The upper part of the figure is the m_b histogram, where four false alarms (or incorrect detections) are not shown. The lower part of the figure is the Gaussian detection probability curve which had been corrected by the correct decision probability before fitting the Gaussian parameters. Therefore, the curve is lower in detection probability and shifted to the right on the m_b scale relative to the observed data.

Summarizing all results, Table IV-4 shows the estimated Gaussian parameters for central Eurasian events in November 1974. As a result of the correction, these are about 0.30 m_b units higher than the results in Table IV-3. Thus the results in Table IV-4 compared to those in Table IV-2 are 0.7 magnitude units lower for the Fisher detector and 0.4 magnitude units lower for the conventional detector. The average lower magnitudes in this study can mainly be attributed to the use of the much higher false alarm rate. Apparently, the Fisher detector benefitted relatively by 0.4 m_b units by running at the higher false alarm rate. This result may not be valid because of instability of the detector in controlling the false alarm rate as shown by Table IV-9. By comparing with the ABF results, the detectors were only about 0.15 m_b

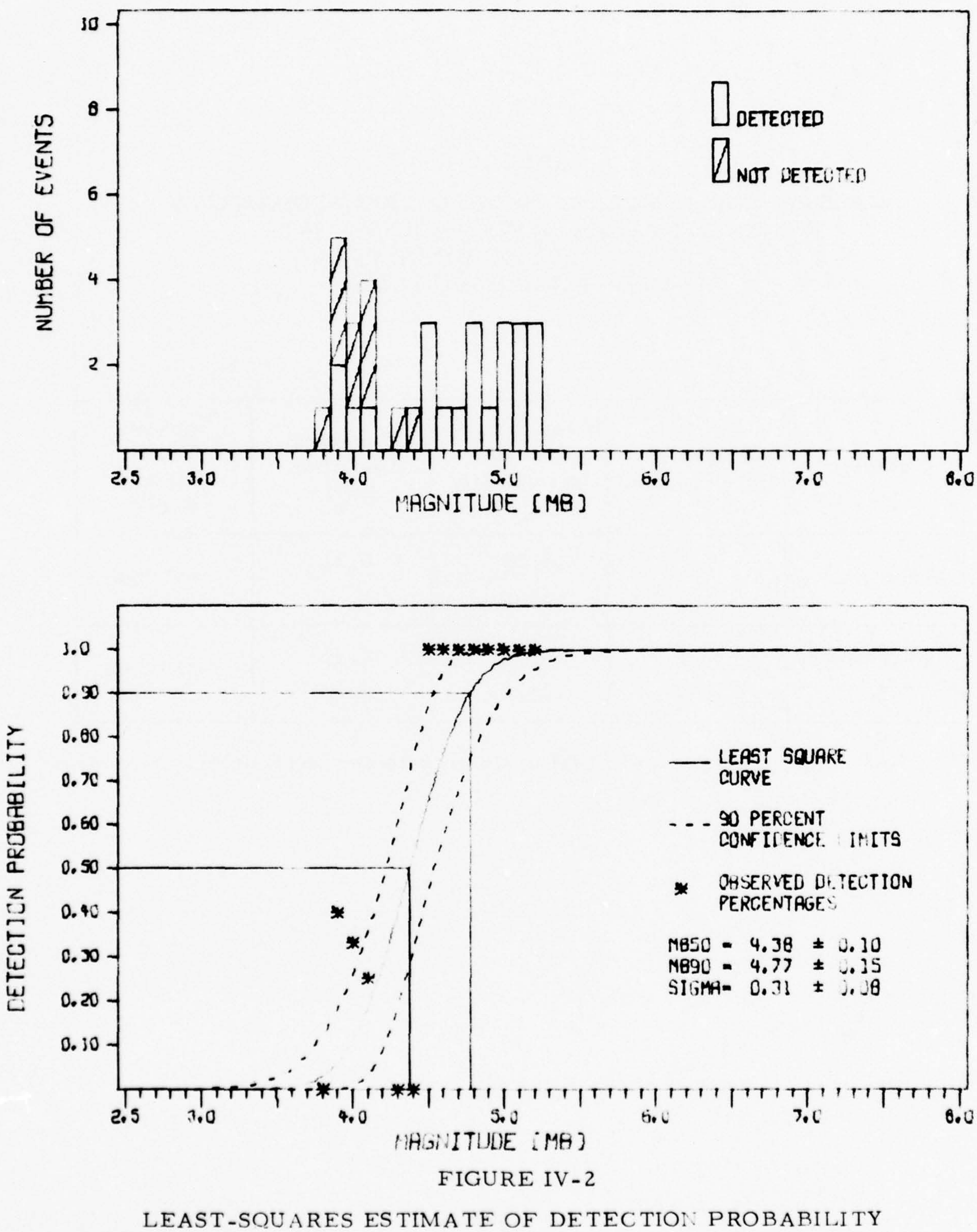

FIGURE IV-2

LEAST-SQUARES ESTIMATE OF DETECTION PROBABILITY
(FISHER DETECTOR, 0.8 SECOND INTEGRATION GATE,
CENTRAL EURASIA, NOVEMBER 1974 DATA)

TABLE IV-4

GAUSSIAN PARAMETERS FOR DETECTION PROBABILITY
(CENTRAL EURASIA, NOVEMBER 1974 DATA,
30 SECOND DETECTION WINDOW, AND
12-MINUTE WARM-UP TIME)

Detector	Integration Gate (second)	Mean or 50 Percent Detectability (m_b)	Standard Deviation (m_b)	Constant False Alarm Rate*
Fisher	0.8	4.38	0.31	5 per hour
	1.6	4.39	0.44	
Conventional Power	0.8	4.39	0.43	5 per hour
	1.6	4.34	0.40	

* CFAR - prescribed constant false alarm rate per beam or single sensor.

units poorer at the 50 percent detectability level. This further confirms the high false alarm rates caused by reducing the number of beams formed in detector algorithms. A word of caution, the detection probability estimation was based on a relatively small ensemble of events.

C. DETECTION PERFORMANCE IN WINTER

Upon receiving the new 1976 data from the KSRS array, the evaluation of detectors' performance in the winter was started by using January 15 to February 20 data. Three regions were selected: south Eurasia (240° and 270° beams), central Eurasia (300° and 330° beams), and Kurile-Kamchatka (20° and 50° beams). Only two beams were formed for each region with the same 15.1 km/sec velocity (50° epicentral distance) for all. The whole event ensemble was processed again using the single-site (usually site 1) data.

Processed were a total of 181 events in which the south Eurasian region had 38, central Eurasia 44, and Kurile-Kamchatka 99. Body-wave magnitude distributions for the event ensemble in south Eurasia and central Eurasia were anomalous, and their Gaussian probability estimate resulted in an unusually large standard deviation. However, the Kurile-Kamchatka region had a relatively larger ensemble of events which were also processed by use of the adaptive beamforming program. The detectors' correct decision probability was obtained for this region.

As an illustration, Figure IV-3 shows the least-squares estimate of detection probability for the conventional power detector with the 0.8 second integration gate. The upper part of the figure illustrates the m_b histogram, where eight events were considered as false alarms (incorrect receptions) and were not included there. The lower part of the figure shows the least-squares estimate of detection probability curve.

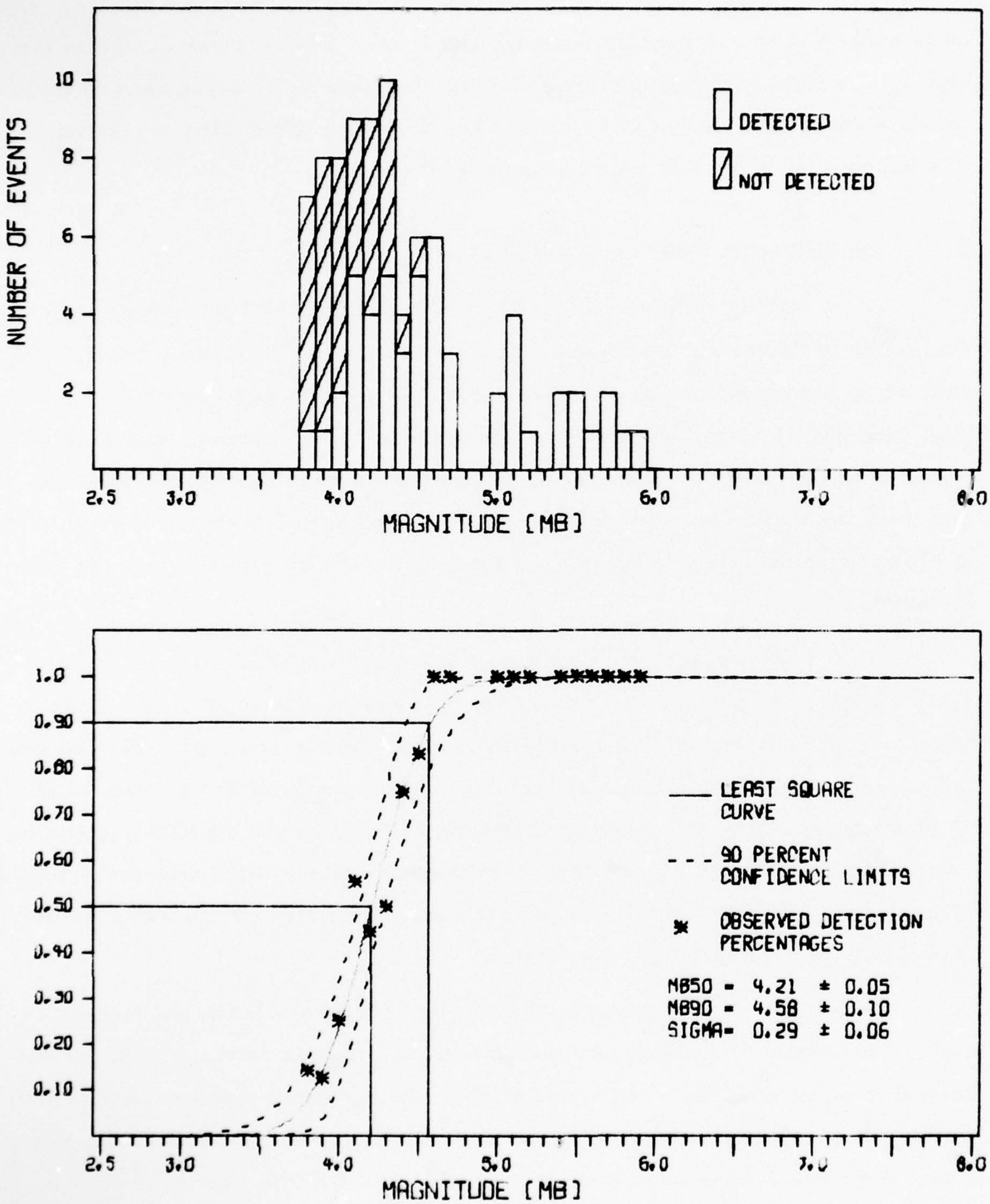

FIGURE IV-3

LEAST-SQUARES ESTIMATE OF DETECTION PROBABILITY (CONVENTIONAL POWER DETECTOR, 0.8 SECOND INTEGRATION GATE, KURILE-KAMCHATKA, JANUARY AND FEBRUARY 1976 DATA)

Summarizing all the results, Table IV-5 illustrates a set of the Gaussian parameters for detection probability. The table indicates that: (a) the conventional power detector is equal to or slightly superior to the Fisher detector, and (b) single-sensor detectability is almost as good as the array. As previously mentioned, these results are influenced by difficulties with the detector in specifying and controlling the false alarm rate. It is obvious that magnitude capabilities cannot be compared and have little meaning unless the false alarm rate can be specified and controlled to meet those specifications. This means the detector design must be improved.

The present detectors' detection logs were also checked against the analyst's picks (KSRS detection logs provided by VELA Seismological Center, Alexandria, Virginia). On the basis of the Kurile-Kamchatka event ensemble, the detectors in general yielded more detections (12 more for conventional power detector using 1.6 second gate) than the analysts. This could be due to the fact that the detectors operated at lower thresholds, resulting in more detections (most weak signals) and tolerating more false alarms. In fact, the analyst's picks might be at a near-zero false alarm level.

Combining the data in the three regions, the 181 events were estimated with least-squares fitting to the Gaussian parameters by the method presented in Section III. Figure IV-4 shows the estimate for the Fisher detector with the 1.6 second integration gate, while Table IV-6 lists the Gaussian parameters of estimated detection probability for the whole set of winter data. The table indicates that the 50 percent detectability ranged from 4.2 to 4.4 m_b, with the 1.6 second integration gate seemingly superior to the 0.8 second integration gate. The prescribed false alarms are indicated in Table IV-6. The realized false alarms may be considerably at variance with prescribed false alarms.

TABLE IV-5

GAUSSIAN PARAMETERS FOR DETECTION PROBABILITY
(KURILE-KAMCHATKA, JANUARY AND FEBRUARY 1976 DATA,
40 SECOND DETECTION WINDOW,
AND 12-MINUTE WARM-UP TIME)

Detector	Integration Gate (second)	Mean or 50 Percent Detectability (m_b)	Standard Deviation (m_b)	Constant False Alarm Rate *
Fisher	0.8	4.34	0.43	5 per hour
	1.6	4.19	0.27	
Conventional Power (array)	0.8	4.21	0.29	5 per hour
	1.6	4.19	0.25	
Single-Sensor Power	0.8	4.27	0.38	10 per hour
	1.6	4.25	0.32	

* CFAR - prescribed constant false alarm rate per beam or single sensor.

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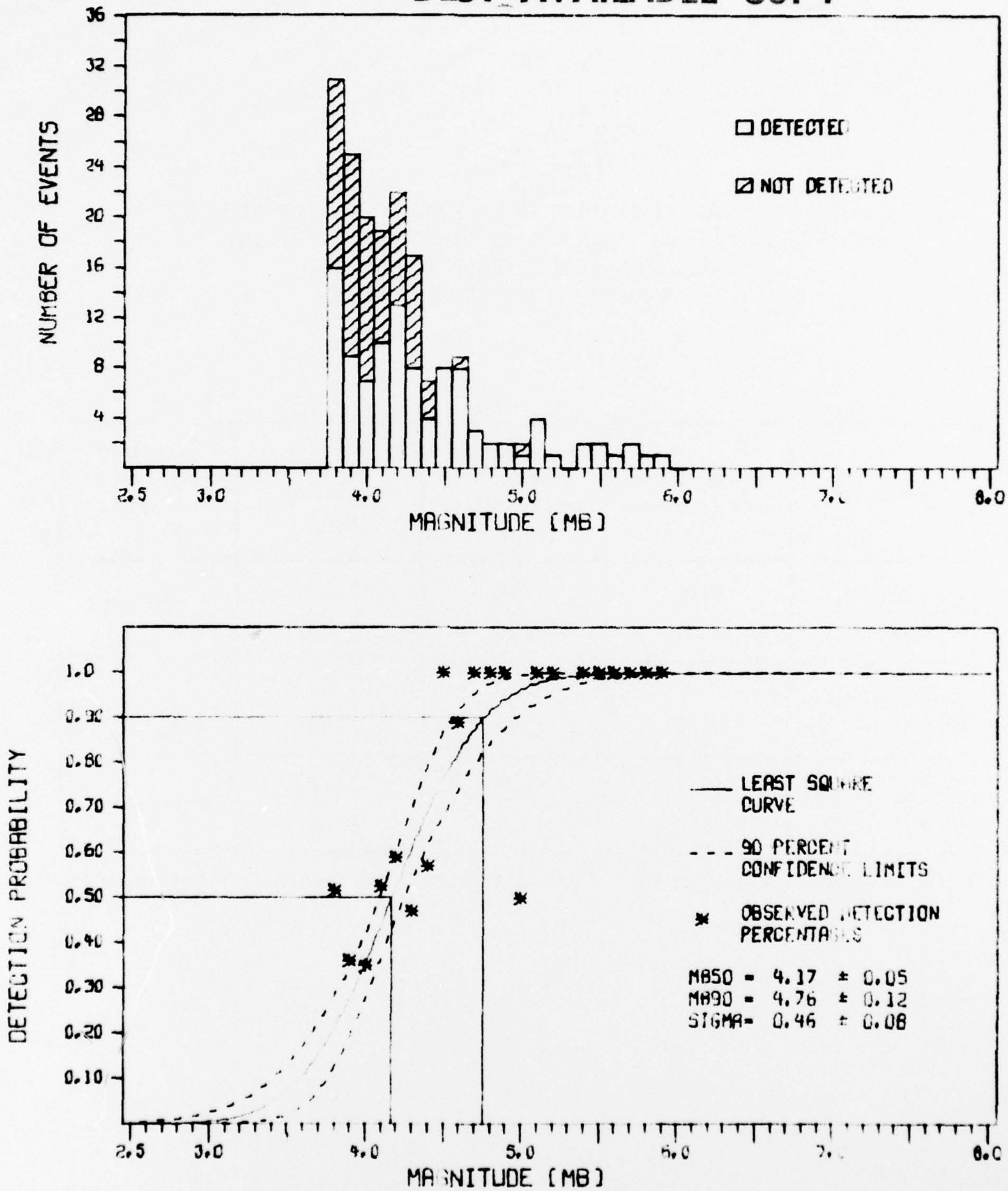

FIGURE IV-4

LEAST-SQUARES ESTIMATE OF DETECTION PROBABILITY
(FISHER DETECTOR, 1.6 SECOND INTEGRATION GATE,
JANUARY AND FEBRUARY 1976 DATA)

TABLE IV-6

GAUSSIAN PARAMETERS FOR DETECTION PROBABILITY
(ALL REGIONS, JANUARY AND FEBRUARY 1976 DATA,
40 SECOND DETECTION WINDOW,
AND 12-MINUTE WARM-UP TIME)

Detector	Integration Gate (second)	Mean or 50 Percent Detectability (m_b)	Standard Deviation (m_b)	Constant False Alarm Rate *
Fisher	0.8	4.35	0.55	5 per hour
	1.6	4.17	0.46	
Conventional Power	0.8	4.19	0.53	5 per hour
	1.6	4.18	0.43	
Single-Sensor Power	0.8	4.29	0.71	10 per hour
	1.6	4.26	0.66	

* CFAR - prescribed constant false alarm rate per beam or single sensor.

D. TIME ACCURACY MEASUREMENTS

The detected times issued by the automatic detectors were analyzed by comparing them with the ABF results. Only central Eurasian events in November 1974 and Kurile-Kamchatka events in January and February 1976 were available for the comparison. Table IV-7 presents a computation of averaged absolute time difference between the ABF results and the automatic detectors' detected time. The table indicates that the conventional power detector was superior to the Fisher detector and the single-sensor time accuracy was the poorest. There was a tendency for the Fisher detector's detected time to be later than that of the ABF results.

E. DETECTOR RESPONSE PATTERN

Detector response patterns were measured for a Grecian event taken from November 1974 data and for a number of Kurile-Kamchatka events in 1976. Figure IV-5 shows the Fisher detector output pattern with the 0.8 and 1.6 second integration gates for the event from Greece. Three curves corresponding to the 20 km per second, 15 km per second, and 10 km per second velocities used in beamforming are shown with the dots indicating the source location (velocity-azimuth space). The same illustration for the conventional power detector is presented in Figure IV-6. Comparison of the results between Figures IV-5 and IV-6 shows greater off-beam losses for the Fisher detector than for the conventional detector.

Table IV-8 presents the beamforming loss measurements for six events in Kurile-Kamchatka in January and February 1976. The dB values in the table are the differences of detector outputs between the exact location beamforming (azimuth and epicentral distance being computed from a Norwegian Seismic Array (NORSAR) bulletin and included in the table) and the fixed detector beamforming (50° azimuth and 50° epicentral distance) used in the evaluation for these events whose bodywave magnitudes ranged from 4.0 to 5.8.

TABLE IV-7

TIME ACCURACY MEASUREMENTS* FOR
THE AUTOMATIC DETECTORS' DETECTED TIME

Data Base	Fisher Detector		Conventional Power Detector		Single-Sensor Power Detector	
	0.8 second	1.6 second	0.8 second	1.6 second	0.8 second	1.6 second
Central Eurasia Nov 1974	5.75	5.45	3.65	3.68	--	--
Kurile-Kamchatka Jan-Feb 1976	5.54	4.79	2.73	2.75	6.22	5.43

* Absolute difference between ABF results and automatic detectors' detected times in seconds.

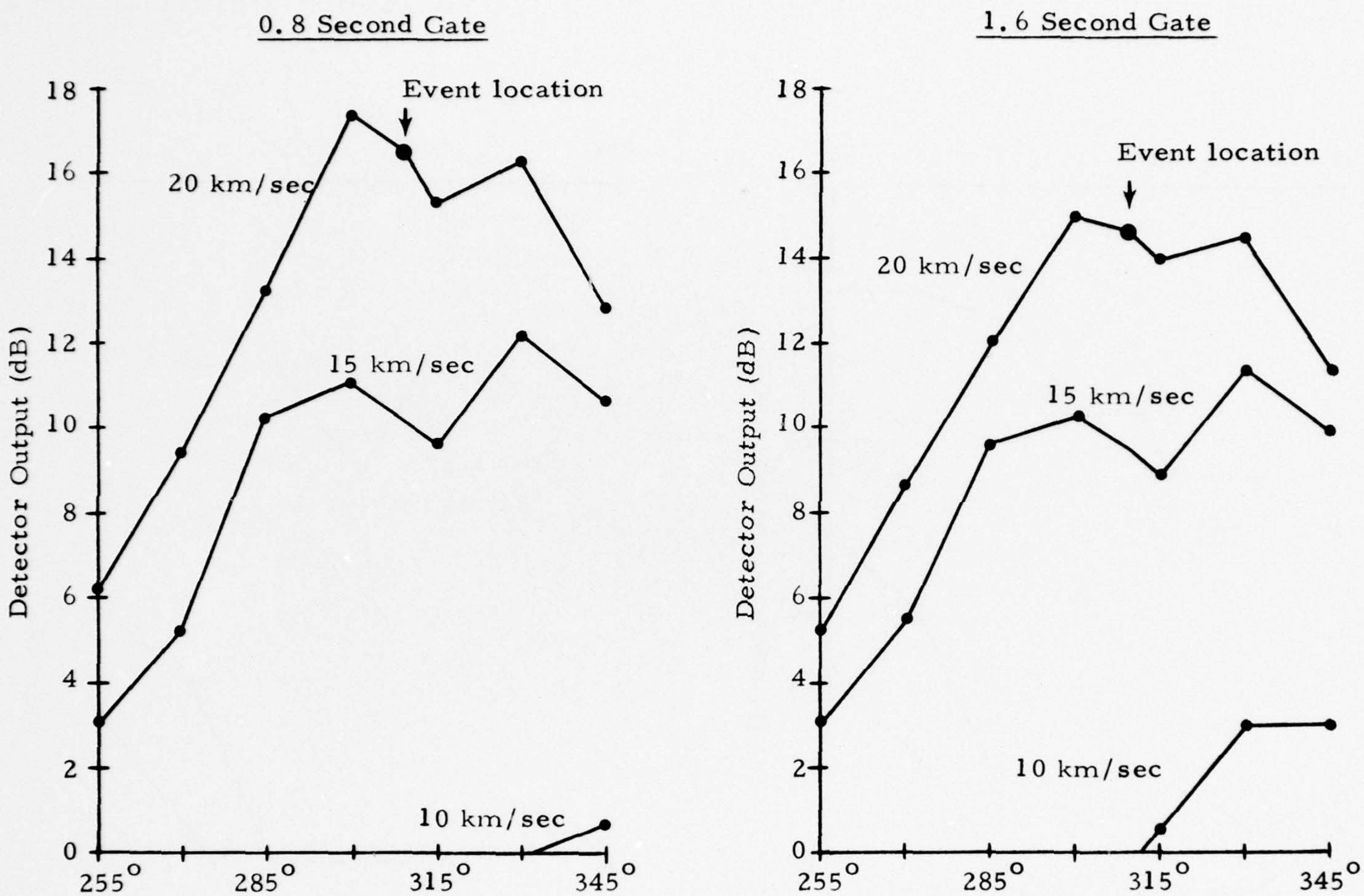

FIGURE IV-5

FISHER DETECTOR RESPONSE FOR AN EVENT FROM GREECE

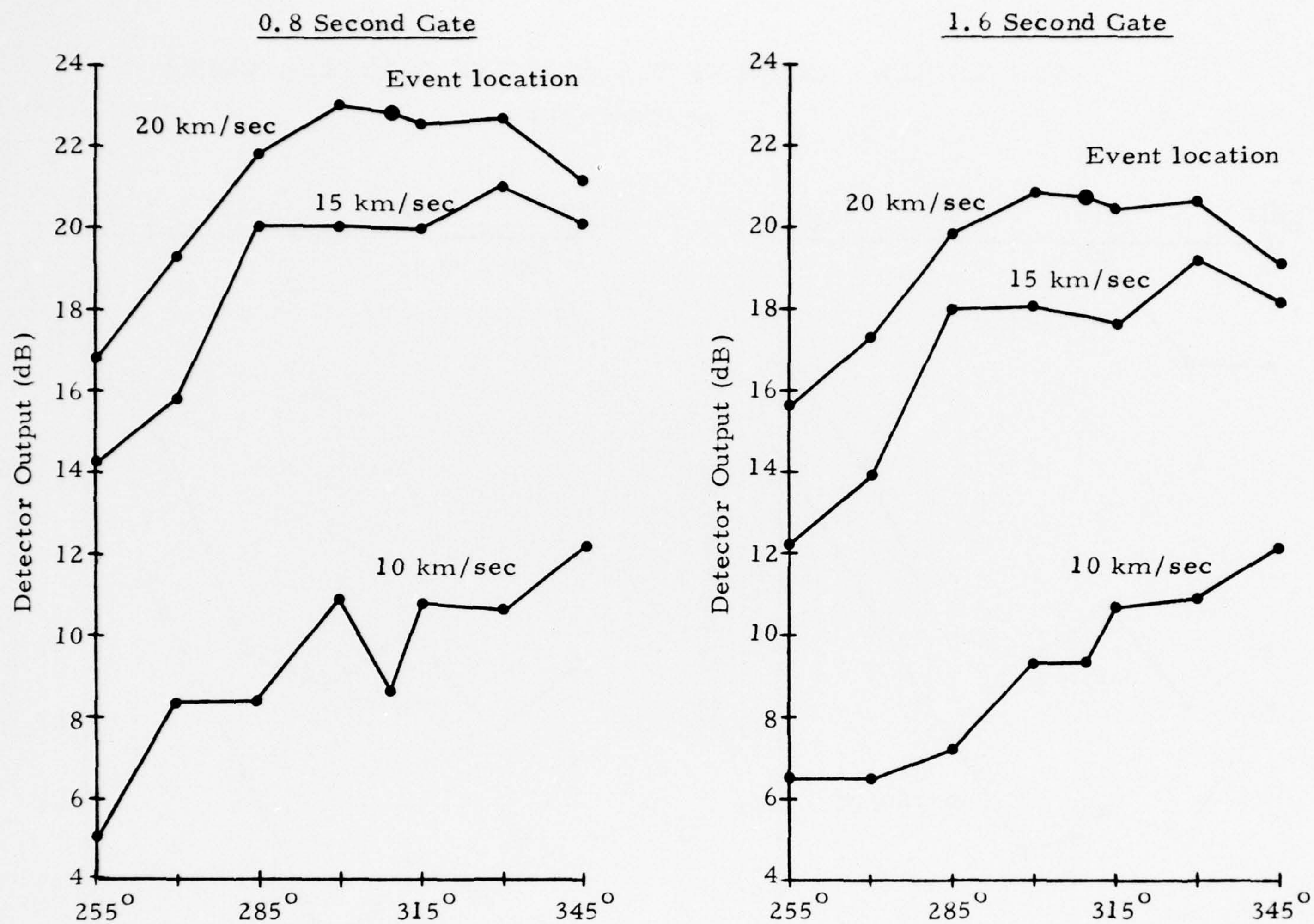

FIGURE IV-6

CONVENTIONAL POWER DETECTOR RESPONSE FOR AN EVENT FROM GREECE

The present array beams in the detector suffered two steps of beamforming loss. First, the lack of signal amplitude similarity across the array created amplitude degradation even if an exact steering location was used. Second, steering the array to an approximate location additionally degraded the amplitude. In the first case, amplitude degradation can be measured for a strong amplitude signal (defined as being visible on single-sensor data) and measurements were done by Prahl et al. (1975). But for the lower amplitude signals (invisible on single-sensor) there is no method to provide the effective measurements. In the second case, the results of measurements presented in Table IV-8 indicate signal losses of 4 dB for the Fisher detector and 2 dB for the conventional power detector.

F. FALSE ALARMS

Presented in Table IV-9 are the false alarm counts within 51 minutes (9 minutes for the warm-up period) of processing for three noise samples. Two beams (20° and 50°) were formed for the Fisher and the conventional power detectors. Two time constants, 90 seconds and 600 seconds, were used to exponentially smooth the long-term averages in the conventional detector. The detectors were operated continuously in the hour-long processing by suppressing the 'dead time' when alarms were triggered.

From the data, single-sensor results did show more alarms than the array beam. On the basis of ABF processing results or arrival times, the detector outputs were re-examined by use of an 11 second detection gate (4 seconds before and 7 seconds after ABF processing results of arrival time, as suggested by Snell (1976)). Table IV-10 presents the Gaussian detection probability estimate of the results. The conventional power detector results still stay at much the same performance as the 40 second detection gate. In this case, the conventional beam detector operates significantly better (6 dB in detectability) over the single-sensor. For the

TABLE IV-8

BEAMFORMING LOSS MEASUREMENTS FOR SIX EVENTS IN KURILE-KAMCHATKA, JANUARY AND FEBRUARY 1976

Event Number	Fisher (dB)		Conventional Power (dB)		Event Azimuth	Event Epi-central Distance	m_b
	0.8 sec gate	1.6 sec gate	0.8 sec gate	1.6 sec gate			
1	7.1	7.8	5.0	4.6	59°	19°	4.2
2	6.5	6.6	2.1	1.8	57°	17°	5.7
3	3.2	5.3	0.9	1.5	64°	17°	5.8
4	0.4	1.2	0.4	0.3	61°	17°	4.6
5	2.6	0.7	0.7	0.1	55°	18°	4.0
6	3.0	3.4	1.5	1.8	57°	18°	4.6

TABLE IV-9

ALARM COUNTS FOR HOUR-LONG NOISE SAMPLES

Noise Sample	Smoothing Constant*	Fisher		Conventional Power		Single-Sensor Power	
		0.8 sec	1.6 sec	0.8 sec	1.6 sec	0.8 sec	1.6 sec
025/08:30:00 to 025/09:30:00	90 seconds	10	10	11	17	13	12
	600 seconds	10	10	8	11	10	12
033/18:30:00 to 033:19:30:00	90 seconds	10	13	7	7	14	11
	600 seconds	10	13	11	9	14	13
037/21:00:00 to 037/22:00:00	90 seconds	10	4	5	6	10	10
	600 seconds	10	4	5	4	10	8

* Exponentially weighted average of past detector outputs.

TABLE IV-10

GAUSSIAN PARAMETERS FOR DETECTION PROBABILITY (11 SECOND DETECTION GATE, KURILE-KAMCHATKA, JANUARY AND FEBRUARY 1976 DATA)

Detector	Integration Gate (second)	Mean or 50 Percent Detectability (m_b)	Standard Deviation (m_b)
Fisher	0.8	4.71	0.80
	1.6	4.42	0.48
Conventional Power	0.8	4.23	0.34
	1.6	4.36	0.41
Single-Sensor Power	0.8	4.78	0.77
	1.6	4.64	0.59

Fisher detector, a poorer performance than the conventional power detector was obtained, because the Fisher detector sometimes failed to pick up the correct arrival times as stated earlier in Subsection III-D.

SECTION V
CONCLUSIONS

The Fisher detector and the conventional power detector were evaluated for their detection performance on the basis of constant alarm rate design operated at 10 false alarms per hour for the sum of all beams. A total of 330 events in November 1974 and January and February 1976 was used as a data base. Major results are summarized here, followed by discussions and suggestions for possible improvements.

A. MAJOR RESULTS

- For the central Eurasian region, the 50 percent detectable bodywave magnitude was about 4.4 m_b on the basis of autumn data (Table IV-4) with an expected false alarm rate of five per hour per beam for the Fisher and conventional power detectors. For the Kurile-Kamchatka region, the 50 percent detectable bodywave magnitude was about 4.2 m_b for the conventional power detector and about 4.3 m_b for the Fisher detector on the basis of winter data (Table IV-5) with an expected false alarm rate of five per hour per beam. This also holds for the whole Eurasian region (Table IV-6). A single-sensor power detector (using Site 1) had 50 percent detectability at 4.3 m_b with an expected false alarm rate of ten per hour. These are lower magnitude capabilities than those obtained by Black and Lane (1975) because the detector was operated at a higher false alarm rate for this study.

- Using the ABF processing results as references for obtaining the signal arrival times and allowing a narrower 11-second window for detection, the Kurile-Kamchatka events were re-estimated and yielded 50 percent detectability at about 4.6 m_b for the Fisher detector, 4.3 m_b for the conventional power detector and 4.7 m_b for the single-sensor power detector (Table IV-10).

- Compared with the analyst's picks (detection logs of the Korean Seismic Research Station), the Fisher detector and the conventional power detector yielded more detections. In fact, on the basis of the present data ensemble, the analyst-picked events were all detected by the conventional power detector using 1.6 second gate. The false alarm rates of analysts are not known sufficiently well for a comparison.

B. DIFFERENCE BETWEEN THE TWO DETECTORS

On the basis of detection probability measurements and estimates (in terms of bodywave magnitude) and the time-accuracy study, the conventional power detector appeared to be superior to the present Fisher detector. Because both detectors have the same numerator in the mathematical algorithms, any difference in performance must come from the denominators. The conclusion that the conventional power detector can detect a signal more accurately than the Fisher detector lies in the fact that the algorithm in the conventional power detector was successful in freezing the long-term average (LTA, the denominator) upon the signal arrivals. The denominator in the Fisher detector computes the amplitude variance across the array. When signal similarity is not perfect, the signal component of variance degrades the performance of the Fisher detector significantly. One contribution which harmfully enlarges the denominator of the Fisher detector is the single-sensor signal amplitude variations across the array. Average

amplitude variation at KSRS short-period array, as measured by Prahl et al. (1975) was 1.3 dB.

C. SUGGESTIONS FOR FURTHER WORK

From the knowledge and experience gained in this study, the following suggestions are made:

- The present version of the constant alarm rate automatic detection algorithm should be changed to improve threshold control.
- The present use of a one minute dead time after detection should be avoided to prevent missing signals occurring by chance after a false alarm or in the coda of a preceding event.
- More work seems needed to avoid erroneous multiple-azimuth detections of large signals and false alarms.
- Steering to maximum beam power should be used to avoid large signal losses due to incorrect azimuth and propagation velocity.

SECTION VI

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